National Transportation Safety Board
Aviation Accident Final Report

Location:	Selma, CA	**Accident Number:**	WPR18LA021
Date & Time:	10/30/2017, 1416 PDT	**Registration:**	N88MV
Aircraft:	METCALFE ROBERT B VANS RV 6	**Aircraft Damage:**	Substantial
Defining Event:	Loss of engine power (total)	**Injuries:**	1 None
Flight Conducted Under:	Part 91: General Aviation - Personal		

Analysis

The pilot reported that about 25 minutes into the local personal flight in the experimental amateur-built airplane, with all systems appearing to operate normally, he noticed that the batteries (located near his right foot) were getting hot and that the system voltage indicated about 15.5V, which was above the normal value of about 13V. Almost immediately thereafter, the engine lost total power. The pilot activated the bus manager emergency power switch and independently selected each of the two engine control units but was unable to restore engine power. He chose a rural road for a forced landing but changed his path to clear a truck on the road; the airplane impacted a vineyard on the side of the road, nosed over, and came to rest inverted.

The pilot had recently decided to change the carburetor and conventional magneto ignition systems to electronic versions for "performance and efficiency improvements." He purchased a kit that included an electronic fuel injection system and replaced the magnetos himself with a fully electronic ignition system.

After completing the installations, the pilot began testing the systems and engine operation. Two days before the accident flight, he conducted two flights of the airplane with the new systems; both flights were brief and uneventful.

Postaccident examination revealed no anomalies with the airplane fuel system or the engine itself. Because the engine was completely reliant on electricity for operation and control of the ignition and fuel injection, the cause of the engine power loss was likely due to a problem with the electrical system or supply. The only nonimpact-related anomaly discovered during the engine and airframe examination was that the swage/crimp of the terminal to the conductor of the primary alternator ground cable was loose, and the conductor and terminal bore evidence (black residue) of electrical arcing. The appearance was consistent with that residue having been caused by the looseness of the swage/crimp and as having been loose for an extended period before the accident. This looseness and arcing indicated that there were transient power interruptions. Such interruptions also create the potential for spurious electrical power variations, which could potentially interfere with the operation of the airplane's electrical or electronic systems, including the alternator, batteries, bus manager, and both the fuel injection and ignition systems.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The pilot's failure to properly secure an alternator ground cable swage that led to problems with the electrical system and/or electronic engine controls, which resulted in a total loss of engine power.

Findings

Aircraft	Electrical pwr sys wiring - Damaged/degraded (Cause)
Personnel issues	Modification/alteration - Owner/builder (Cause)

Factual Information

History of Flight

Enroute-descent	Electrical system malf/failure
	Loss of engine power (total) (Defining event)
Emergency descent	Off-field or emergency landing

On October 30, 2017, about 1416 Pacific daylight time, a Vans Aircraft experimental, amateur built RV-6 airplane, N88MV, impacted a fence in a vineyard during a forced off-airport landing near Selma, California. The airline transport pilot was uninjured. The wings and fuselage incurred substantial damage. The airplane was registered to and operated by the pilot as a Title 14 *Code of Federal Regulations* Part 91 personal flight. Visual meteorological conditions prevailed at the time of the accident and no flight plan had been filed. The local flight originated from Fresno Chandler Executive Airport (FCH), Fresno, California about 1346.

According to the pilot, after takeoff, he proceeded west to climb above the Fresno Yosemite International Airport (FAT), Fresno, California and verified his transponder operation with Fresno Approach. He then headed towards the west/southwest. About 15 to 20 minutes later, the pilot began a descent to get below the FAT Class C airspace, and return to FCH. At an altitude of about 4,000 ft, the pilot noticed that the airplane batteries, located in the cockpit near his right foot, were getting hot. The pilot switched the engine monitor display to check the electrical system values, and saw that the indicated voltage was 15.5 volts, and that the indicated current was just above 30 amperes. At that point, the engine suddenly lost all power, but the propeller continued to windmill.

The pilot made some abbreviated and unsuccessful attempts to restore power, but then turned his attention to landing the airplane. He determined that the nearest airport was Selma Airport (0Q4), Selma, California which was about 10 miles away, and he began a gliding descent towards that airport. He communicated his situation and plans to a Fresno Approach controller. When the airplane altitude was about 1,000 ft, the pilot determined that he would not be able to reach 0Q4, and selected a road as his intended off-airport landing site. At that time, the only traffic on that road was an oncoming truck, but as the pilot continued the descent, he became uncertain whether the airplane would have sufficient altitude to clear the truck. The pilot then offset his flight path to the side of the road, in order to ensure that he would clear the truck. The truck passed the airplane, and the pilot then turned left and underflew some powerlines in an attempt to line up with, and land on, the road. That effort was unsuccessful, and the airplane touched down in a vineyard on the other side of the road. The airplane nosed over, and came to rest inverted. The pilot escaped the airplane by breaking the canopy. Although there was fuel leaking from the airplane, there was no fire. Federal Aviation Administration (FAA) inspectors examined the airplane at the site, and the airplane was recovered and transported to a secure facility for further examination.

Pilot Information

Certificate:	Airline Transport; Flight Instructor; Commercial	**Age:**	36, Male
Airplane Rating(s):	Multi-engine Land; Single-engine Land	**Seat Occupied:**	Left
Other Aircraft Rating(s):	None	**Restraint Used:**	
Instrument Rating(s):	Airplane	**Second Pilot Present:**	No
Instructor Rating(s):	Airplane Multi-engine; Instrument Airplane	**Toxicology Performed:**	No
Medical Certification:	Class 1 Without Waivers/Limitations	**Last FAA Medical Exam:**	10/04/2017
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	10/02/2017
Flight Time:	2700 hours (Total, all aircraft), 300 hours (Total, this make and model), 2150 hours (Pilot In Command, all aircraft), 62 hours (Last 90 days, all aircraft), 21 hours (Last 30 days, all aircraft), 1 hours (Last 24 hours, all aircraft)		

The pilot held commercial, airline transport, and flight instructor certificates, and airplane single- and multi-engine land and instrument ratings. He reported a total flight experience of 2,700 hours, including 300 hours in the accident airplane make and model. His most recent flight review was completed October 2017, and his most recent FAA first-class medical certificate was also issued in October 2017.

Aircraft and Owner/Operator Information

Aircraft Make:	METCALFE ROBERT B	**Registration:**	N88MV
Model/Series:	VANS RV 6 UNDESIGNAT	**Aircraft Category:**	Airplane
Year of Manufacture:	2000	**Amateur Built:**	Yes
Airworthiness Certificate:	Experimental	**Serial Number:**	24874
Landing Gear Type:	Tailwheel	**Seats:**	2
Date/Type of Last Inspection:	10/25/2017, Condition	**Certified Max Gross Wt.:**	1600 lbs
Time Since Last Inspection:	1 Hours	**Engines:**	1 Reciprocating
Airframe Total Time:	1422 Hours at time of accident	**Engine Manufacturer:**	LYCOMING
ELT:	Installed, activated, aided in locating accident	**Engine Model/Series:**	O-360-A3A
Registered Owner:	On file	**Rated Power:**	180 hp
Operator:	On file	**Operating Certificate(s) Held:**	None

The airplane was constructed in 2000 by another individual, and that individual sold it to the accident pilot in February 2013. At the time of the pilot's purchase, the airplane was equipped with a Lycoming O-360 series engine, and a Hartzell 2-blade constant speed propeller. According to the pilot, when he acquired the airplane, the airframe and engine had each accumulated a total time (TT) in service of 1,100 hours. The pilot put about 300 hours more on the airplane, and then decided to modify it with some significant system and engine changes.

The pilot reported that the engine of the as-purchased airplane was equipped with a carburetor and a conventional magneto ignition system. He decided to change those systems to electronic versions for "performance and efficiency improvements." The pilot purchased a non-certificated kit that included an electronic fuel injection system, and replaced the magnetos with a fully electronic ignition system. The kit included the necessary wiring diagrams and instructions. The pilot performed the installations, and he reported that he had very few questions (of the manufacturers or vendors) regarding the installation details.

The pilot also reported that the as-purchased airplane had a "very basic visual flight rules (VFR) avionics package" that he replaced with an updated avionics suite. He purchased and installed a Garmin G3X system that presented flight instrumentation, position, navigation, communication, and other information using flat-panel color display(s). He purchased a pre-fabricated wiring harness to help expedite his G3X installation effort. He also installed two EARTHX-brand lithium-ion batteries as part of the modifications. None of these components met any FAA technical approvals such as Technical Standard Orders (TSO), nor were they required to do so.

About 5 weeks before the accident, the pilot had essentially completed the avionics and engine modifications, and then began ground runs of the engine and avionics in order to configure and test the new installations. Prior to the accident flight, he had put about 1.5 to 2 hours of ground run time on the engine, and had also conducted two uneventful but brief test flights. The accident flight was the third flight with the new systems, and the engine power loss occurred about 25 minutes into that flight.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual Conditions	**Condition of Light:**	Day
Observation Facility, Elevation:	FCH, 280 ft msl	**Distance from Accident Site:**	10 Nautical Miles
Observation Time:	1415 PDT	**Direction from Accident Site:**	360°
Lowest Cloud Condition:	Clear	**Visibility**	9 Miles
Lowest Ceiling:	None	**Visibility (RVR):**	
Wind Speed/Gusts:	Calm /	**Turbulence Type Forecast/Actual:**	/ None
Wind Direction:		**Turbulence Severity Forecast/Actual:**	/ N/A
Altimeter Setting:	29.77 inches Hg	**Temperature/Dew Point:**	23°C / 12°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Fresno, CA (FCH)	**Type of Flight Plan Filed:**	None
Destination:	Fresno, CA (FCH)	**Type of Clearance:**	None
Departure Time:	1345 PDT	**Type of Airspace:**	Unknown

The 1415 automated weather observation at FCH, located about 10 miles north of the accident location, included calm winds, visibility 9 miles, clear skies, temperature 23° C, dew point 12° C, and an altimeter setting of 29.77 inches of mercury.

Wreckage and Impact Information

Crew Injuries:	1 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	N/A	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	1 None	**Latitude, Longitude:**	36.572500, -119.754722 (est)

The airplane came to rest inverted in a vineyard, about 6 miles west of 0Q4. The pilot was able to exit due to the resting attitude of the airplane, which allowed sufficient ground clearance beneath the canopy. The fuselage, wings and horizontal stabilizers sustained substantial damage.

During the initial post-accident inspection by FAA personnel, no non-impact related damage was noted. The fuel tanks were not compromised, and they contained sufficient fuel for continued flight.

The alternator was an automotive model with an integral voltage regulator. The nut and stud assembly that was used to attach the primary alternator ground cable to the alternator was found to be secure, and the cable terminal was securely attached to that stud. However, the swaging of the ground cable to that terminal was loose. Black residue, consistent with arcing and fretting, was present at the conductor-to-terminal junction. The appearance was consistent with that residue having been caused by the looseness of the crimp (swage), and as having been loose for an extended period prior to the accident.

The cockpit circuit breaker for the alternator was rated at 60 amperes. It was the flush-when-set type, without the tall head that would allow manual tripping (breaking the circuit) by the pilot. The circuit breaker was found in the non-tripped position.

No other pre-impact anomalies with the airplane or engine were observed. The G3X device was removed from the airplane and sent to the NTSB facilities in Washington DC for data download.

Additional Information

G3X Data

The G3X device was successfully downloaded by NTSB personnel. The resulting dataset contained 91 parameters, including date, time, flight information (position, speed, heading etc), autopilot information, and engine/system information. The data captured multiple airplane power-up sessions on 12 different days. The data began on September 26, 2017, and included all three flights reported by the pilot, including the accident flight on October 30, 2017.

Flight Summaries

The data indicated that the pilot conducted two separate flights on October 28, 2017, followed by the accident flight on October 30. The airborne segment of the first flight subsequent to the installation of the new engine systems lasted about 5 minutes. The second flight was initiated about 70 minutes later, and its airborne segment lasted for about 10 minutes. The accident flight was conducted 2 days later, and lasted about 30 minutes.

Engine Performance and Power Loss

Recorded system and engine parameters included voltage (V), current (A), exhaust gas temperature (EGT), cylinder head temperature (CHT), manifold, oil, and fuel pressure, fuel flow, RPM, and "power." Except for "power," which was a derived/calculated value, all other engine parameters were measured values. The exact locations in the electrical system where the voltage and current were measured was not determined by the investigation.

Aside from the voltage and current data streams, no anomalies were observed with any of the engine parameters prior to the power loss. As indicated by multiple parameters, the engine ceased operating at 1411:02, and the power loss was essentially instantaneous.

Review of all available voltage data indicated that nominal system voltage was about 13.1V to 13.5V for all ground and flight modes. Excluding the accident flight, the highest recorded voltage value was 13.5V. On the accident flight, the nominal voltage was about 13.8V. About 3 minutes before the engine stopped producing power, the voltage began to rise, and reached a peak value of 16.3V. The engine stopped producing power within a few seconds of that voltage peak, and the voltage decreased to 13.5V about 7 seconds later. The voltage then gradually decreased to 12.8V by the end of the flight, which was about 5 minutes later.

For all three flights, on takeoff, the current values rose rapidly to about 30A, remained near 30A for climbs and level flight, but then decreased to about 18A during descents. On the accident flight, the current initially fluctuated somewhat, but then remained very stable at about 30A for the 15 minute-period just prior to the time that the voltage began to rise. Once the voltage started to rise, the current also started to rise, and climbed to a peak value of 33A. The first data line that indicated that the engine had stopped also indicated that the current had simultaneously and instantaneously decreased to a value of 0A. The current remained at 0A for the remainder of the flight.

Electrical Provisions and Failure Modes

Electrical problems or failures can result in a complete loss of engine power in airplanes equipped with fully electronic ignition or fuel-control systems, but there are several hardware or system-architecture approaches to reduce the possibility of a complete engine power loss. These include equipment redundancy (eg dual batteries, dual alternators, etc), alerting systems/indicators, and circuitry isolation mechanisms.

The pilot reported that both of the lithium-ion batteries were equipped with non-pilot-controlled over-voltage protection circuitry, and his conclusion was that that protection had not activated on the accident flight. He based that determination on the fact that the LED lights on the batteries that indicated activation of the protection circuitry had not illuminated. This was not able to be independently verified during the investigation. The airplane was equipped with a single alternator with an integral voltage regulator, but the alternator's cockpit circuit breaker did not trip, and the pilot was unable to take the alternator off-line due to the circuit breaker design.

The pilot purchased the ignition/fuel injection kit from Protek Performance, a vendor of aftermarket engine components for non FAA-certificated (experimental) aircraft and aircraft engines. The kit components were from manufacturers of aftermarket components for non FAA-certificated aircraft engines. The kit included dual SDS-brand engine control units (ECUs), an SDS Programmer, and an SDS crankshaft trigger for spark timing. The engine conversion retained the dual ignition system concept, which included two spark plugs per cylinder, with each spark plug powered by one of the two separate ECUs.

The pilot had equipped the airplane with a FlyEFII-brand "bus manager" which included an emergency power switch. FlyEFII-published information contained the following verbiage about the system:
"The Bus Manager was designed to provide a protected "essential power bus" for vehicles that rely upon critical electronic equipment for safe operation. This includes aircraft with electronic ignition or electronic fuel injection systems. The Bus Manager creates a protected 12 volt power source to ensure that these critical systems keep working during vehicle operation...The Bus Manager system, when fully implemented manages a two battery vehicle power system plus additional emergency power circuit paths to provide triple redundant protection of essential bus powered systems."

According to FlyEFII documentation, relevant functions of the Bus Manager include:
- Triple redundant Essential Bus protection.
- Built-in Essential Bus and Main Bus relays.
- Alternator charge isolation for two-battery system.
- Emergency Power Switch (pilot-actuated) function provides third level of Essential Bus protection.

FlyEFII published the following information regarding the operation of the Bus Manager overvoltage protection:
"If you have a voltage reading above 15.2V, your regulator has failed and your overvoltage protection in the plane will be activated if you have this safety feature. If your over voltage protection in the plane fails, the batteries over voltage protection will engage. In this scenario, the battery does not disconnect but instead blocks the excess current/voltage into the battery. If you see high voltage and amperage readings, you should immediately take your alternator off line to avoid damage to your electronics and possibly damage to the battery. The BMS protection has limitations and is designed to protect your battery, not your electronics."

Review of the manufacturer's wiring diagram for the bus manager indicated that with the alternator still on line (producing electricity, and circuit breaker not tripped) but with the batteries off line (due to their internal protective circuitry), selection of the emergency power switch to "ON" will provide alternator-produced DC power to the essential bus.

The arcing signatures on the loose alternator ground cable swage were consistent with transient power interruptions. Transient power interruptions can create the potential for spurious electrical power variations. Spurious power variations can exceed the design tolerance levels for the electrical equipment. Power interruptions and variations can adversely affect the operation of electronic components, with unknown results.

Pilot Actions

The investigation did not locate any applicable checklists or other procedural guidance to be used in the event of engine problems or a complete engine power loss in this airplane as configured for the accident flight.

The pilot reported that prior to the accident, when tested on the ground and in the air, the dual ECUs functioned correctly, both independently and jointly. During the accident flight, the engine was operating in the normal mode on both ECUs when the engine power loss occurred. After the engine power loss, the pilot selected each of the ECUs independently, but engine power was not restored.

The batteries powering the system could be pilot-selected either independently or jointly. The pilot reported that if "the battery overvoltage protection" would have triggered, it would have "shut that battery down and I would lose the avionics that didn't have a self-contained backup battery. I would [have had to] switch to the other battery to get [the avionics] back online." All the avionics continued to function normally after the engine power loss, with no battery switching by the pilot.

The pilot reported that the "bus manager blocks the voltage from going to the battery but it doesn't block the power from going to the ignition system (which is what failed). In the event that the bus manager fails the emergency power switch is used to bypass [the bus manager] and send power directly from the battery to the [electronic fuel injection and ignition] system."

The pilot reported that he did try the emergency power switch but that engine power was not restored. The pilot reported that "everything was wired per the drawings," but he could not specifically recall what other systems (in addition to fuel injection and ignition) were powered by the essential bus. The drawings referenced by the pilot were not obtained or examined by the investigators.

Finally, the pilot reported that he "wasn't really able to pinpoint a single point of failure in the system." He also reported that in communications with a Protek Performance representative, the representative stated that the fuel injection and ignition systems should not have been adversely affected by the observed voltage and current values.

Administrative Information

Investigator In Charge (IIC):	Michael C Huhn	**Report Date:**	05/28/2020
Additional Participating Persons:	Fritz Bayer; FAA; Fresno, CA Bjorn Beijens; FAA; Fresno, CA		
Publish Date:	05/28/2020		
Note:	The NTSB did not travel to the scene of this accident.		
Investigation Docket:	http://dms.ntsb.gov/pubdms/search/dockList.cfm?mKey=96264		

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The Independent Safety Board Act, as codified at 49 U.S.C. Section 1154(b), precludes the admission into evidence or use of any part of an NTSB report related to an incident or accident in a civil action for damages resulting from a matter mentioned in the report. A factual report that may be admissible under 49 U.S.C. § 1154(b) is available here.